SUSPENSION DESIGN FOR ATTENUATION OF DISK FLUTTER INDUCED TRACK MIS-REGISTRATION OF A HARD DISK DRIVE BY MANIPULATION OF THE HINGE AND/OR LOAD BEAM

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to disk drives. More particularly, the present invention relates to disk drives, head stack, gimbal and suspension assemblies that include structures that contribute to reducing disk flutter induced track mis-registration ("TMR").

Description of the Prior Art

A typical hard disk drive includes a head disk assembly ("HDA") and a printed circuit board assembly ("PCBA"). The HDA includes at least one magnetic disk ("disk"), a spindle motor for rotating the disk, and a head stack assembly ("HSA") that includes a slider with at least one transducer or read/write element for reading and writing data. The HSA is controllably positioned by a servo system in order to read or write information from or to particular tracks on the disk. The typical HSA has three primary portions: (1) an actuator assembly that moves in response to the servo control system; (2) a head gimbal assembly ("HGA") that extends from the actuator assembly and biases the slider toward the disk; and (3) a flex cable assembly that provides an electrical interconnect with minimal constraint on movement.

A typical HGA includes a load beam, a gimbal attached to an end of the load beam, and a slider attached to the gimbal. The load beam has a spring function that provides a "gram load" biasing force and a hinge function that permits the slider to follow the surface contour of the spinning disk. The load beam has an actuator end that connects to the actuator arm and a gimbal end that connects to the gimbal that supports the slider and transmits the gram load biasing force to the slider to "load" the slider against the disk. A rapidly spinning disk develops a laminar airflow above its surface that lifts the slider away from the disk in opposition to the gram load biasing force. The slider is said to be "flying" over the disk when in this state.

A challenge faced by hard disk drive designers and manufacturers as they continually increase the capacities of contemporary hard disk drives is the phenomenon known as Non

Repeatable Run Out ("NRRO"). NRRO, either written into the data tracks (usually denoted "RRO") or occurring live during drive operation, manifests itself as radial displacements of the read/write head(s) relative to the data tracks of the disk(s), caused by vibrations of either the HSA or disk pack (inc. spindle motor, disk(s), spacer(s), and clamp). As the storage capacity of magnetic disks increases, the number of data tracks per inch ("TPI") is increased, or conversely, the track width is decreased, leading to greater data density per unit area on the magnetic media. Since NRRO may degrade the data transfer performance to and from the magnetic media by increasing, for example, the frequency of off track errors, the ratio of RMS NRRO to track width must be maintained at a fairly constant value; thus, designers must ensure that NRRO decreases in proportion to track width. Since disk flutter (or out of plane vibrations of the disk induced by turbulent airflow within the drive) TMR is the dominant contributor to NRRO, reducing disk flutter TMR will correspondingly decrease NRRO. In turn, decreasing NRRO may enable higher TPI to be reliably achieved.

What are needed, therefore, disk drives, head stack and gimbal assemblies, suspensions and load beams configured to reduce disk flutter induced TMR.

SUMMARY OF THE INVENTION

This invention may be regarded as a head stack assembly for a disk drive having a disk, the head stack assembly including a body portion; an actuator arm cantilevered from the body portion; a hinge, a first surface of the hinge being coupled to the actuator arm; a load beam having a first end and a second end, the first end being attached to a second surface of the hinge, the second surface facing away from the first surface; a gimbal coupled to the second end of the load beam, and a slider coupled to the gimbal.

The present invention is also a disk drive, including a disk having a recording surface; a head stack assembly, including a body portion; an actuator arm cantilevered from the body portion; a hinge, a first surface of the hinge being coupled to the actuator arm; a load beam having a first end and a second end, the first end being attached to a second surface of the hinge, the second surface facing away from the first surface; a gimbal coupled to the second end of the load beam, and a slider coupled to the gimbal.

According to another embodiment thereof, the present invention is also a head gimbal

assembly for a head stack assembly of a disk drive, the head stack assembly including a body portion, an actuator arm cantilevered from the body portion, the disk drive having a disk, including a hinge, a first surface of the hinge being coupled to the actuator arm; a load beam having a first end and a second end, the first end being attached to a second surface of the hinge, the second surface facing away from the first surface; a gimbal coupled to the second end of the load beam, and a slider coupled to the gimbal.

The present invention is also a suspension for a head stack assembly of a disk drive, the head stack assembly including an actuator arm and a mount plate. The suspension includes a hinge, a first surface of the hinge for coupling to the actuator arm; a load beam having a first end and a second end, the first end being attached to a second surface of the hinge, the second surface facing away from the first surface, and a gimbal coupled to the second end of the load beam.

The present invention may also be viewed as a suspension for a head stack assembly of a disk drive, the head stack assembly including a body portion, an actuator arm cantilevered from the body portion, the disk drive having a disk, including a load beam having a first end and a second end, the first end defining an integral hinge portion, the hinge portion defining a radius geometry that may include at least two radii of curvatures configured to lower load beam toward the disk, a first surface of the hinge portion being coupled to the actuator arm, and a gimbal coupled to the second end of the load beam.

The present invention, according to a still further embodiment thereof, is a head gimbal assembly for a head stack assembly of a disk drive, the head stack assembly including a body portion, an actuator arm cantilevered from the body portion, the disk drive having a disk, the head gimbal assembly including a load beam having a first end and a second end, the first end defining an integral hinge portion, the hinge portion defining a radius geometry that may include at least two radii of curvatures configured to lower load beam toward the disk, a first surface of the hinge portion being coupled to the actuator arm, and a gimbal coupled to the second end of the load beam, and a slider coupled to the gimbal.

Another embodiment of the present invention is a head stack assembly for a disk drive having a disk, the head stack assembly including a body portion; an actuator arm cantilevered from the body portion; a load beam having a first end and a second end, the first end defining an

integral hinge portion, the hinge portion defining a radius geometry that may include at least two radii of curvatures configured to lower load beam toward the disk, a first surface of the hinge portion being coupled to the actuator arm; a gimbal coupled to the second end of the load beam, and a slider coupled to the gimbal.

The present invention may also be viewed as a disk drive, including a disk having a recording surface; a head stack assembly, including a body portion;an actuator arm cantilevered from the body portion; a load beam having a first end and a second end, the first end defining an integral hinge portion, the hinge portion defining a radius geometry that may include at least two radii of curvatures configured to lower load beam toward the disk, a first surface of the hinge portion being coupled to the actuator arm, and a gimbal coupled to the second end of the load beam, and a slider coupled to the gimbal.

According to another embodiment thereof the present invention is a head stack assembly for a disk drive having a disk, the head stack assembly including a body portion; an actuator arm cantilevered from the body portion; a hinge defining a radius geometry, the radius geometry including at least two radii of curvatures, the hinge being coupled to the actuator arm; a load beam having a first end and a second end, the first end being coupled to the hinge; a gimbal coupled to the second end of the load beam, and a slider coupled to the gimbal.

The invention is also a disk drive including a disk having a recording surface; a head stack assembly, including a body portion; an actuator arm cantilevered from the body portion; a hinge defining a radius geometry, the radius geometry including at least two radii of curvatures, the hinge being coupled to the actuator arm; a load beam having a first end and a second end, the first end being coupled to the hinge; a gimbal coupled to the second end of the load beam, and a slider coupled to the gimbal.

According to another embodiment, the present invention is a head gimbal assembly for a head stack assembly of a disk drive, the head stack assembly including a body portion, an actuator arm cantilevered from the body portion, the disk drive having a disk, the head gimbal assembly including a hinge defining a radius geometry, the radius geometry including at least two radii of curvatures, the hinge being coupled to the actuator arm; a load beam having a first end and a second end, the first end being coupled to the hinge; a gimbal coupled to the second end

end of the load beam, and a slider coupled to the gimbal.

The present invention is also a suspension for a head stack assembly of a disk drive, the head stack assembly including an actuator arm and a mount plate, the disk drive having a disk. The suspension includes a hinge defining a radius geometry, the radius geometry including at least two radii of curvatures, the hinge for coupling to the actuator arm; a load beam having a first end and a second end, the first end being coupled to the hinge, and a gimbal coupled to the second end of the load beam.

In the disk drives, head stack, gimbal and suspension assemblies according to the present invention, the radius geometry may include a first radius of curvature, a second radius of curvature and a third radius of curvature, the first radius being closer to the mount plate than the second radius, the second radius being closer to the mount plate than the third radius. The third radius may be greater than the second radius.

The disk drives and head stack assemblies may also include a mount plate attached to the actuator arm. The hinge may be coupled to the actuator arm via the mount plate, which mount plate may have a thickness that is greater than 0.22 mm. The hinge may have a thickness that is greater than 0.05 mm. The load beam may have a thickness that is greater than 0.12 mm.

The foregoing and other features of the invention are described in detail below and set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 depicts the geometry of a disk of a hard disk drive.

Fig. 2 shows a side view of a head gimbal assembly (HGA) in which the load beam pitch angle α_s is identified.

Fig. 3 is a plan view of a disk and a Head Stack Assembly (HSA) according to an embodiment of the present invention.

Fig. 4A shows a side view of a HGA, according to an embodiment of the present invention.

Fig. 4B is an enlarged view of a portion of Fig. 4B in conjunction with a disk.

Fig. 5 shows a side view of a HGA, according to another embodiment of the present invention.

Fig. 6 shows a side view of a HGA, according to a still further embodiment of the present invention.

Fig. 7 shows a side view of a HGA, according to another embodiment of the present invention.

Fig. 8 is an exploded view of a hard disk drive, according to an embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 8 shows the principal components of a magnetic disk drive 800 constructed in accordance with the present invention. With reference to Fig. 8, the disk drive 800 comprises a HDA 844 and a PCBA 814. The HDA 844 includes a base 816 and a cover 817 attached to the base 816 that collectively house a disk stack 823 that includes a plurality of magnetic disks (of which only a first disk 811 and a second disk 812 are shown), a spindle motor 813 attached to the base 816 for rotating the disk stack 823, an HSA 820, and a pivot bearing cartridge 884 (such as a stainless steel pivot bearing cartridge, for example) that rotatably supports the HSA 820 on the base 816. The spindle motor 813 rotates the disk stack 823 at a constant angular velocity. The HSA 820 comprises a swing-type or rotary actuator assembly 830, at least one HGA 810, and a flex circuit cable assembly 880. The rotary actuator assembly 830 includes a body portion 840, at least one actuator arm 860 cantilevered from the body portion 840, and a coil portion 850 cantilevered from the body portion 840 in an opposite direction from the actuator arm 860. The actuator arm 860 supports the HGA 810 that, in turn, supports the slider(s) (see Figs. 4A, 4B, 5, 6 and 7) according to the present invention. The flex cable assembly 880 may include a flex circuit cable and a flex clamp 859. The HSA 820 is pivotally secured to the base 816 via the pivot-bearing cartridge 884 so that the slider at the distal end of the HGA 810 may be moved over the surfaces of the disks 811, 812. The pivot-bearing cartridge 884 enables the HSA 820 to pivot about a pivot axis, shown in Figs. 8 and 3 at reference numeral 882. The storage capacity of the HDA 844 may be increased by, for example, increasing the track density (the TPI) on the

disks 811, 812 and/or by including additional disks in the disk stack 823 and by an HSA 820 having a vertical stack of HGAs 810 supported by multiple actuator arms 860.

The "rotary" or "swing-type" actuator assembly comprises a body portion 840 that rotates on the pivot bearing 884 cartridge between limited positions, a coil portion 850 that extends from one side of the body portion 840 to interact with one or more permanent magnets 892 mounted to back irons 870, 872 to form a voice coil motor (VCM), and an actuator arm 860 that extends from an opposite side of the body portion 840 to support the HGA 810. The VCM causes the HSA 820 to pivot about the actuator pivot axis 882 to cause the slider and the read write transducers thereof to sweep radially over the disk(s) 811, 812. The HGA 810 includes a load beam and a gimbal coupled to the load beam, as detailed below.

Fig. 3 is a plan view of a disk 811, 812 and a head stack assembly 820, according to an embodiment of the present invention. As shown therein, the skew angle is defined as the angle of the slider (best shown at 412 in Figs. 4A, 4B, 5, 6 and 7) relative to a tangent to the data tracks recorded on the recording surface of the disk 811, 812. With reference to Fig. 3, the skew angle is shown as the angle formed between the longitudinal axis 310 of the head stack assembly 820 passing through the slider and the data track tangent 320. The data track tangent is parallel to the tangential direction e_θ that is at a 90-degree angle relative to the radial direction e_r. As defined herein and shown in Fig. 3, the skew angle is positive in the clockwise direction. The head stack assembly 820 of Fig. 3 may include one or more of the structures that are shown in figures 4A, 4B, 5, 6 and 7 (and/or combinations and variants thereof) and that are described herein below.

Total disk flutter TMR, which is the radial position error between the read/write transducer heads and the data track of a hard disk drive due to disk vibrations, is the summation (in the time domain) of four components; namely, disk deformation, suspension pitching, and slider pitching and rolling. That is,

$$TMR_{total} = TMR_{pitch} + TMR_{roll} + TMR_{disk} + TMR_{suspension} \qquad (1)$$

Fig. 1 depicts the geometry of a disk 811 or 812 of a hard disk drive, such as shown at 800 in Fig. 8. The disk 811, 812 is clamped at the inner diameter (ID) thereof at clamp 106 and free at the outer diameter (OD) thereof. In Fig. 1, α_r is the angular orientation of the disk 811,

812 in the radial direction and t_d is the thickness of the disk 811 or 812. As shown the disk 811 or 812 may undergo deformation, causing the neutral axis of the disk 811, 812 to deviate relative to the radial direction r by an angle α_r.

Fig. 2 shows a side view of a HGA to illustrate the pitch angle α_s. In Fig.2, the pitch angle α_s is measured from the plane of the mount plate 210, or other suspension mounting surface of/to the actuator arm, to the load beam. The pitch angle α_s is positive as shown in Fig. 2.

As shown in Figs. 1 and 2 the disk and suspension TMR is modeled herein as

$$TMR_{disk} = \frac{t_d}{2}\sin(\alpha_r) \quad (2)$$

and

$$TMR_{suspension} = \sin(skew) l_5 \left[\cos\left(\sin^{-1}\left(\frac{l_5 \sin(\alpha_s) - z}{l_5} \right)\right) - \cos(\alpha_s) \right] \quad \text{(See Figs. 1, 2 and 3)} \quad (3)$$

where

z is the disk displacement from the undeformed state;

l_5 is the distance from the suspension RG (radius geometry) to the dimple (reference numeral 204 in Fig. 2);

t_d is the thickness of the disk;

α_r is the angular orientation of the disk in the radial direction;

α_s is the pitch angle of the suspension load beam relative to the mount plate, and

skew is the skew angle as shown in Fig. 3.

Restricting the r-dependence of z to monotonically increasing or decreasing, or zero-valued, functions (only modes of practical importance are considered, i.e. those with zero nodal circles) of r, then

$$\left[\{z > 0\} \Leftrightarrow \{\alpha_r > 0\},\ \{z = 0\} \Leftrightarrow \{\alpha_r = 0\},\ \{z < 0\} \Leftrightarrow \{\alpha_r < 0\} \right], \quad (4)$$

for an arbitrary instant in time and angular location on the disk.

From Equation (2), it may be shown that minimizing $|\alpha_s|$ will minimize $TMR_{suspension}$ (regardless of skew angle), and therefore may reduce the total disk flutter induced TMR. Furthermore, if $\alpha_s < 0$, it may be proven from equations (1)-(4) that $TMR_{suspension}$ and TMR_{disk} are perfectly out-of-phase at negative skew angles (disk OD, where worst total disk flutter TMR typically occurs), and therefore at least partial cancellation of terms occurs, further reducing the total disk flutter TMR. Although there are four components that contribute to disk flutter TMR, only the suspension component is a function of α_s; therefore, although the present invention only considers cancellation of disk and suspension TMR, the present invention may be extended to cover cancellation between the portions of slider pitch and roll TMR that are in-phase with disk TMR, i.e. the total disk flutter TMR may be considered solely as it varies with α_s, without loss of generality.

The present invention includes a number of embodiments for mitigating the effects of disk flutter induced TMR. As collectively shown in Figs. 8 and 4A, the present invention, according to one embodiment thereof, is a disk drive in which the HGA is configured such that the load beam is attached below the hinge, which is in turn placed below the mount plate (also called the swage plate), thereby lowering the mount plate end of the load beam and reducing the pitch angle α_s (including negative values). It may be shown that disk flutter TMR has a minimum for sufficiently negative values of α_s, when the actuator is positioned to OD, although geometrical considerations may limit the range of α_s. In particular, since only the suspension TMR is a function of α_s, this minimum corresponds to complete cancellation by the suspension TMR of the portions of disk, slider pitch, and slider roll TMR that are 180° out-of-phase with respect to the suspension TMR.

More generally, the present invention is a disk drive 800 that includes a disk 811, 812 having a recording surface. A head stack assembly 820 includes a body portion 840 and an actuator arm 860 cantilevered from the body portion 840. With specific reference to Fig. 4A, the HGA 400 of the disk drive 800 includes a mount plate 402 attached to the actuator arm 860. The HGA 400 also includes a hinge 404 having a first surface 405 and a second surface 407 that faces away from the first surface 405. The first surface 405 of the hinge 404 is coupled to the mount

plate 402, via swage boss 406 (for example). The load beam 408 of the HGA 400 defines a first end 409 and a second end 411. The first end 409 of the load beam 408 is attached to the second surface 407 of the hinge 404. As best shown in Fig. 4B, a gimbal 416 is coupled to the second end 411 of the load beam 408 and a slider 412 is coupled to the gimbal 416. Fig. 4B shows a dimple 414 formed within the load beam 408 near the second end 411 thereof, although the specific structure of the second end 411 of the load beam 408 shown in Fig. 4B is only exemplary and does not limit the scope of the present invention. Indeed, the second end 411 of the load beam 408 may include most any suitable structure for coupling the gimbal 416 and slider 412 thereto. For example, the structure shown and described in commonly assigned and co-pending US patent application serial number 10/xxx,xxx filed on xx/xx/02 and entitled "Suspension Design For Attenuation Of Disk Flutter Induced Track Mis-Registration Of A Hard Disk Drive By Manipulation Of The Load Beam Pitch Angle", the disclosure of which is incorporated herewith by reference may be advantageously incorporated into the disk drives, HSAs, HGAs and suspensions disclosed herein.

The effect of mounting the load beam 408 on the second surface 407 of the hinge 404 lowers the first end 409 of the hinge, which reduces the pitch angle α_s. In turn, reducing α_s lowers the disk flutter TMR at the disk OD, as shown above. The TMR may be further lowered by manipulating the dimensions of the dimple 414 or of the feature at the second end 411 of the load beam 408 to which the gimbal 416 and the slider 412 are attached. Indeed, the disk flutter TMR at the disk OD may be also lowered by raising the second end 411 of the load beam 408, which also reduces the load beam pitch angle α_s. For example, the dimple 414 may be formed with an extraordinarily large outer radius r_o and/or extraordinarily small dimension l_d, such that the outer (spherical, for example) surface 415 of the dimple 414 extends extraordinarily low (i.e., toward the recording surface of the disk 811, 812), thereby raising the second end 411 of the load beam 408 and reducing the load beam pitch angle α_s and consequently the disk flutter induced TMR at the disk OD. The lowering of the first end 409 and/or the raising of the second end 411 thereof relative to the disk 811, 812 are subject to the available space between top of the hinge 203 in Fig. 2 and the disk 711, 712, among other constraints. This space is shown in Fig. 2 at reference numeral 214.

Fig. 5 shows a HGA 500 according to another embodiment of the present invention. This embodiment features a hinge 508 with a double or triple-formed radius geometry. In this embodiment, there are two primary radii of curvature: radius r_2 corresponds to a concave portion of the hinge 508, while r_3 corresponds to a convex portion of the hinge 508. Moreover, because $r_3 >> r_2$, for a given vertical force between the slider 412 and the disk, the angular deformation of the convex curve r_3 will be much greater than that of the concave curve r_2. This force is the gramload, which may be about 2.5 g, nominal. Variations in this force will be chiefly caused by vibrations of the disk, i.e. disk flutter. Thus, the concave curve r_2 acts to statically lower a first end 509 of the load beam 508, further reducing the load beam pitch angle α_s and the disk flutter induced TMR at the disk OD. Either the concave curve r_2 or convex curve r_3 may be located adjacent to the swage plate. Such a hinge 508 may constitute an etched portion of the load beam 408, or may be a separate component attached (e.g., welded) to the load beam 408 and the mount plate 502.

With reference to both Figs. 5 and 8, a disk drive according to the present invention may include a disk 811, 812 having a recording surface; a head stack assembly 820 includes a body portion 840 and an actuator arm 860 cantilevered from the body portion 840. As shown in Fig. 5, the HGA 500 includes a mount plate 402 attached to the actuator arm 860 via swageboss 406; a load beam 408 having a first end 509 and a second end 511. A hinge 508 defines a radius geometry, the radius geometry including at least two radii of curvatures r_2 and r_3. The hinge 508 is coupled to the actuator arm, via the mount plate 402. The first end 509 of the load beam 402 is coupled to the hinge 508. Lastly, a gimbal (reference numeral 416 in Fig. 4B) is coupled to the second end 511 of the load beam 402 and a slider 412 (Fig. 4B) is coupled to the gimbal 416. As shown in Fig. 5, the hinge 508 may be separate from the load beam 402 and attached thereto.

The radius geometry of the hinge 508 may include three radii of curvature. A radius r_1 may be formed immediately adjacent the mount plate 402. Together, radii r_1 and r_2 act to lower the height of the center of curvature of the r_3 radius and, therefore, lower the first end 509 of the load beam 408 while allowing normal welding of the hinge 508 to the mount plate 402. The embodiment of the present invention shown in Fig. 5, therefore, includes a hinge 508 that has a first radius of curvature r_1, a second radius of curvature r_2 and a third radius of curvature r_3. The

first radius r_1 is closer to the mount plate 402 than the second radius r_2 and the second radius r_2 is closer to the mount plate 402 than the third radius r_3. Preferably, the third radius r_3 is greater than the second radius r_2. Advantageously, by lowering the first end of the load beam 408 (thereby bringing it closer to the disk 811, 812), the load beam pitch angle α_s is reduced, along with the disk flutter induced TMR at the disk OD.

The load beam 408 in the HGA 500 of Fig. 5 is mounted on a first surface 512 of the hinge 508. However, to further lower the first end 509 of the load beam 408 relative to the disk 811, 812 to achieve a further reduction in the load beam pitch angle α_s, the configuration of Fig. 6 may be employed. As shown therein, the load beam 408 of the HGA 600 is mounted on a second surface 514 of the hinge 508. This further reduces the load beam 408 and further contributes to lowering the load beam pitch angle α_s.

As shown in Figs. 4A, 5 and 6, the hinge 508 may be a separate element from the load beam 408 and attached thereto. Alternatively, the hinge and the load beam may be formed as a single integral element. Indeed, as shown in Fig. 7, the HGA 700 includes a load beam 708 that has a first end 702 adjacent the mount plate 402 and a second end 704. The first end 702 defines an integral hinge portion 706. In turn, the hinge portion 706 defines a radius geometry that includes at least two radii of curvatures r_2 and r_3 that are together configured to lower load beam 708 toward the disk 811, 812. A first surface 710 of the hinge portion 706 is attached to the mount plate 402. The HGA 700 may also include the r_1 radius as detailed relative to Fig. 5.

Additional benefit, in terms of lowering the load beam pitch angle α_s to reduce the disk flutter induced TMR at the disk OD may be derived from appropriate selection of the thickness (as measured parallel to the axis 882) of the constituent elements of the HGAs shown in Figs. 4A, 4B, 5, 6 and 7. Indeed, the thickness of the mount plate 402 may be selected to be greater than 0.22 mm. The thickness of the hinges 404 and 508, as well as the thickness of the hinge portion 706 may be selected to have a thickness that is greater than 0.05 mm. The thickness of the load beams 408 may also be selected to have a thickness that is greater than 0.12 mm.

The suspension, load beam, hinge features and configurations shown in Figs. 4A, 5, 6 and 7 (and/or various combinations and variants thereof) may be incorporated in the HGA 810 of Fig.

8 to achieve head stacks and disk drives according to the present invention. Advantageously, the present invention, by reducing disk flutter induced TMR and consequently NRRO, enables the TPI of the disks 811, 812 to be increased, thereby enabling the capacity of the drive 800 to be correspondingly increased.